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EXECUTIVE SUMMARY

SEISMIC TESTING OF NATURALLY AGED EXIDE EMP-13 STATION BATTERY CELLS

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A sample of 27 year old lead acid storage batteries from the Shippingport Nuclear Power Station (Shippingport, PA) were tested on a shaker table. The intensity of the shaker tests reached the full capacity of the table. There were no sudden changes in output voltage for any of the seven cells during the stimulated earthquakes. Following the tests, however, the capacity of the cells was found to be sharply reduced. A number of cells were disassembled and examined. Internal components were found to be in poor condition, with loss of negative plate material and generalized corrosion.

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To Mr. B.A. Oliver
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1.0 INTRODUCTION

The large lead-acid storage battery cells that are the subject of this report are used to provide dc power for nuclear power stations during and after an earthquake. It is well known that these cells deteriorate with age and it is normal practice to test them at regular intervals to ensure that they are capable of meeting a specified level of performance. What is not so well understood however, is the effect of age on the mechanical fragility of the cells and whether the cells would be capable of surviving seismic events at the operating basis earthquake (OBE) or safe shutdown earthquake (SSE) levels and to continue to meet the load profile required by the Class 1E system. Because of the importance of storage batteries to the Class 1E system, the US Nuclear Regulatory Commission has requested Sandia National Laboratories (SNL) to evaluate the impact of aging and seismic exposure on battery capacity. Ontario Hydro has been sub-contracted to carry out capacity and seismic shaker tests on naturally aged cells supplied by SNL from several US nuclear power stations (SNL contract 47-4077). The problem addresses possible variations between designs produced by different manufacturers.

This report describes the results of a series of experiments carried out at the Ontario Hydro Research Laboratories on a set of twenty-seven year old Exide EMP-13 cells from the Shippingport Nuclear Power Station (Shippingport, PA). During the shaker tests, no sudden loss of output voltage was recorded, even when the intensity of the shaking reached the limit of the table. However, following the tests, it was found that the capacity (time to discharge) of all of the cells had been reduced sharply. To determine the nature of the damage that was

caused by the shaking, several cells were disassembled for inspection and metallurgical examination. The results indicate that this batch of cells was in generally poor condition with widespread corrosion and damage to the plates.

This report summarizes the test and results for this batch of cells. A more detailed discussion of the tests and results is contained in reports C84-121-P (battery condition and performance)/1/, B84-44-P (seismic test results, single cells)/2/ and 84-428-P (seismic tests, rack mounted cells)/3/.

The tests described here were part of a larger program of testing of aged cells. Other cell types tested to date have included Gould FKR (Pickering NGS)/4,5,6/, Gould NCX2250 (Fitzpatrick NPS)/7/, C&D LCU-13 (North Anna NPS)/9/ and Exide FHC-19 (Calvert Cliffs NPS)/8/.

The Exide EMP-13 cells are of an obsolete type that is no longer being installed in nuclear power plants. They were however the oldest samples of station cells that could be obtained and it was for this reason that they were included in the program.

2.0 TEST METHODS AND RESULTS

2.1 Initial Inspection and Condition

Twelve Exide EMP-13 cells were received from the Shippingport plant. There was no superficial damage, but the cells showed signs of aging, including swollen and warped plates and black precipitate on the bottom of the jars. Our experience with aged station cells suggests that the condition of these cells was consistent with their type and age. The cells were conditioned (charged and discharged several times to stabilize their internal chemical state) and tested for capacity. The electrical state of the cells prior to the seismic tests is summarized in Table 1.

2.2 Seismic Testing - Single Cells

The shaker table and instrumentation used in these experiments is described in Reference 2. The table provides independent motion in three directions. The motion is based on a quasi-random signal, filtered to match the frequency content of a typical earthquake. The duration of each test was 30 seconds. The seismic test method is based on the recommendations of IEEE Std 344-1975 and IEEE Std 501-1978.

For the first phase of the seismic testing, the cells were mounted individually on the shaker table in a stiff frame, designed to minimize relative motion between the cell jar and

the table (see Figure 1). This series was intended to investigate possible failure modes of internal components. The rig was designed to minimize the danger of jar failure and acid spill. Accelerometers were mounted on the base of the frame and on the top of one of the posts of the cell.

Each cell was subjected to a series of tests at successively higher acceleration levels. The test sequence for each cell is shown in the test log given in Table 2. In this record, the acceleration level for each test is quoted in terms of the ZPA fitted IEEE 501 spectrum.

During the seismic tests, the cells were discharged against a resistive load at a one hour discharge rate. They were considered to have passed a seismic test if they remained above 1.75 V during and immediately after the test. The cells were shaken at progressively higher levels up to the machine limit. Each of the four cells that were tested in the single cell frame passed all of the tests. Table 2 provides a log of the test sequence, while Table 3 summarizes the results. Figures 3-14 show response spectra for the final test for each cell. There were no sudden drops in cell voltage during any of the shaker tests.

The seismic test results are presented in this report and in References 2 and 3 in terms of acceleration response spectra of the table motion. To provide a convenient means of comparing the acceleration levels encountered during various tests, each test spectrum is compared to a normalized spectrum defined in IEEE Std 501-1978 /10/. The shape of this spectrum is intended to reflect the frequency content of the "typical" seismic environment for electrical equipment. The intensity of the simulated seismic motion is expressed in terms of the ZPA (zero period acceleration).

2.3 Multi-Cell Rack Test

The single cell tests were designed to focus on failure modes of internal components. To examine the possible failure modes that would be encountered with normal in-plant mounting arrangements, a shaker test was carried out on a set of five cells mounted on a rack that resembled typical seismically qualified battery racks (see Figure 2). The test log and results are shown on Tables 2 and 3. Figures 15-17 show response spectra for the final test with the rack mounted cells. Again, no failures occurred.

For practical reasons, the rack that was used for these tests held only five cells. Full scale racks in power stations are typically much longer. The present tests could be non-conservative since long strings of cells could, under violent shaking, impose large impact loads on cells at the end of the string. These tests provide no positive indication that this is a potential source of trouble. Nevertheless, we suggest that in severe seismic environments, it would be beneficial to separate cells into groups of three or so, with rigid partitions on the rack and flexible electrical connections between groups.

2.4 Post Seismic Capacity Tests and Inspection

Following the shaker table tests the cells were re-tested for electrical capacity. The results of these tests are shown on Table 1. There was considerable loss of discharge capacity for all cells and none were able to meet the acceptance criterion of 80% rated capacity.

Following these tests, four of the cells were disassembled and inspected. It was found that the internal components were in poor condition. On the negative plates, the grid material was cracked and broken near the top of the plates, while a significant proportion of the active material (sponge lead) had apparently been shaken out of the grids by the seismic tests. Plate surfaces were severely pitted and erupted, apparently a result of excessive gassing during service. On the positive plates, there were signs of extensive corrosion. During the shaker tests, a considerable amount of corrosion product had been shaken loose from the plates and in some instances, caused short-circuits between positive and negative plates. Negative bus material was corroded and brittle. Photographs illustrating the post-test condition of the cells can be found in Reference 1.

3.0 CONCLUSIONS

1. The twenty-seven year old Exide EMP13 cells that were the subject of this study were in poor condition. They were all able to survive repeated strong shaking without sudden failures, but had all suffered from major losses in electrical capacity.

2. Internal components of the cells that were disassembled were in poor condition with extensive corrosion and embrittlement. The seismic testing caused corrosion products and active plate material to break away from the plates and lead to a loss in capacity.

3. There were no signs of damage to the jars during any of the tests. This includes tests with multi-cell racks.

4.0 ACKNOWLEDGEMENTS

Test cells for this project were provided by Sandia National Laboratories. This support is gratefully acknowledged. Lloyd Bonzon and Done Hente of SNL are thanked for their large contribution to the project. Within Ontario Hydro, contract co-ordination was handled by the Electrical Design Department. We are grateful to Colin Royce and Jerry Schendel for their efforts. Much of the testing and analysis was carried out by Brian Aucoin of the Chemical Research Department and Gordon Paulson of the Mechanical Research Department. Their able work was essential to the successful outcome of the project.

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9. J.D. Tulk, D.A. Black, W.J. Janis and B.M. Kukreti, "Seismic Testing of Naturally Aged Exide FHC-19 Station Battery Cells". Ontario Hydro Research Division Report No 84-426-K.

10. IEEE Std 501-1978, "IEEE Standard, Seismic Testing of Relays". The Institute of Electrical and Electronics Engineers Inc., 1978.

TABLE 1

CELL CAPACITIES BEFORE AND AFTER SEISMIC TESTING

Cell	Time to 1.75 VPC at 3 h Rate (min)			Per Cent of Rated Capacity at 3 h Rate		
	Pre-Seismic	Post-Seismic*	Post-Seismic Plus Seismic**	Pre-Seismic	Post-Seismic*	Post-Seismic Plus Seismic**
3	151	10	24	84	4	13
4	167	25	39	93	14	22
10	172	25	39	96	14	22
43	177	45	59	98	25	33
45	147	40	54	82	22	30
Avg	163	29	43	91	16	24

* Cells not recharged following seismic testing.

** Capacity during seismic test at 1 h rate converted to 3 h capacity and added to post-seismic capacity, as discussed in Appendix 3.

TABLE 2

TEST LOG OF SEISMIC TESTS ON EXIDE CELLS

Test No	Run No	Cell No	Approx ZPA Level (g) IEEE 501	Comments
1	1	8	0.8	
	2	8	1.0	
	3	8	1.3	
	4	8	1.7	Shaker limit
2	1	1	0.8	
	2	1	1.0	
	3	1	1.3	
	4	1	1.7	Shaker limit
3	1	5	0.8	
	2	5	1.0	Jar clamps came loose. Test stopped.
	3	5	1.0	
	4	5	1.3	
	5	5	1.7	Shaker limit.
4	1	11	0.8	
	2	11	1.0	
	3	11	1.3	
	4	11	1.7	Shaker limit.
Multi-Cell Rack Test (July 26/84) Cells 43, 10, 4, 3, 45				
	1		0.8	
	2		1.0	
	3		1.3	
	4		1.5	No failures.

TABLE 3

MINIMUM ZPA VALUES(g)

Cell	Location	Direction	ZPA
8	base	X	2.18
	base	Y	1.77
	base	Z	1.37
	terminal	X	2.00
	terminal	Y	2.24
	terminal	Z	1.47
1	base	X	1.83
	base	Y	1.56
	base	Z	1.47
	terminal	X	1.84
	terminal	Y	2.00
	terminal	Z	1.63
5	base	X	1.65
	base	Y	1.50
	base	Z	1.50
	terminal	X	1.65
	terminal	Y	1.54
	terminal	Z	2.61
11	base	X	2.16
	base	Y	1.59
	base	Z	1.63
	terminal	X	1.85
	terminal	Y	2.00
	terminal	Z	1.56
43, 10, 4, 3, 45 (rack test)	base	X	1.1
	base	Y	2.17
	base	Z	1.26
	terminal	X	1.31
	terminal	Y	0.8*
	terminal	Z	1.22

* accelerometer malfunction

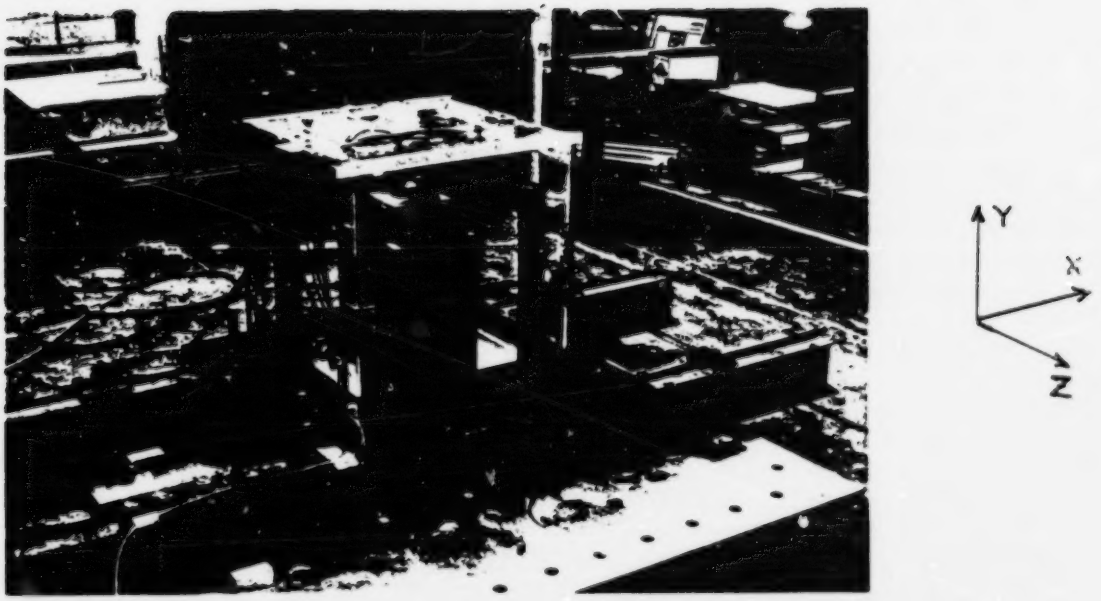


FIGURE 1

MOUNTING ARRANGEMENT FOR SINGLE CELL TESTS
THE CELL IS CLAMPED IN PLACE BY THREADED RODS.
ACCELEROMETERS ARE MOUNTED ON THE BASE AND ON A CELL TERMINAL POST. ACCELEROMETER DIRECTIONS ARE AS INDICATED.

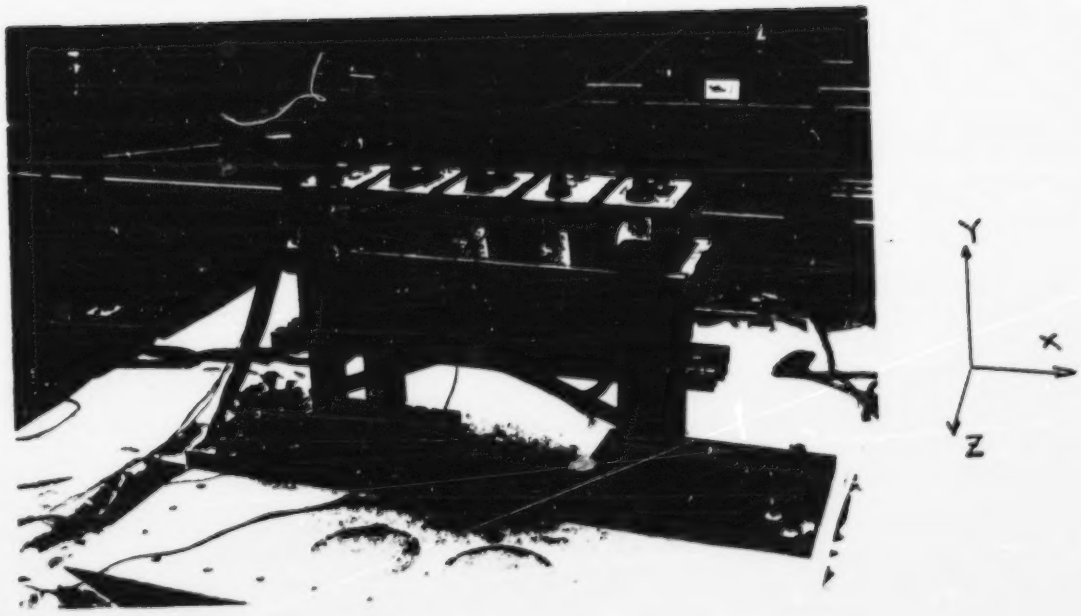
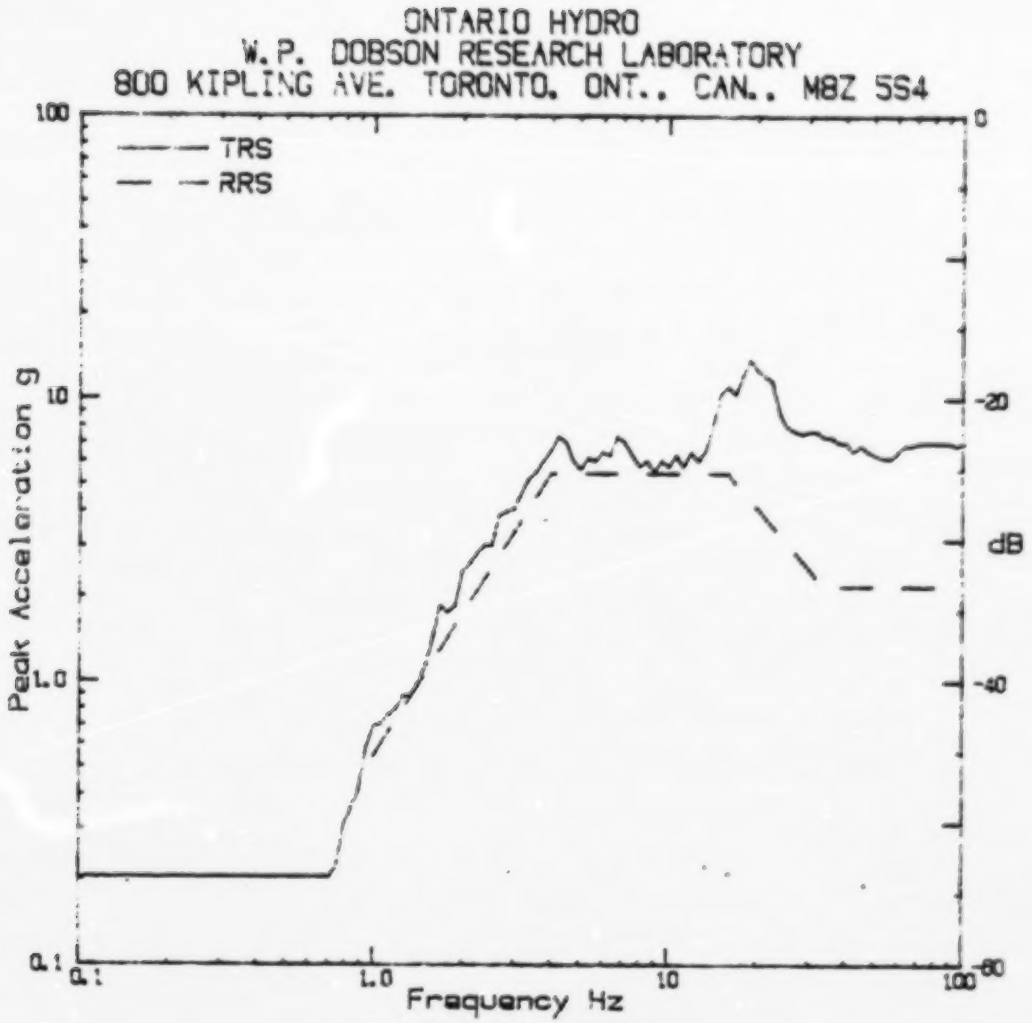


FIGURE 2

MOUNTING ARRANGEMENT FOR BATTERY RACK TESTS ACCELEROMETERS ARE MOUNTED ON THE BASE AND ON A CELL TERMINAL POST. ACCELEROMETER DIRECTIONS ARE AS INDICATED.



RESPONSE SPECTRUM

FIGURE 3

TEST ITEM
Station cells. Exide. Model EMP 13. Serial 8.

PARTICULARS
March 14/84. Time 11:28. Temp(°C) 23. Humidity(%) 39.
Press (kPa) 100.2. Graph 5110

SPECIFICATIONS
Spec: IEEE 501. Conditions span 6.8. voltage & current monitored

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis X
Shaker tri-axial. ZPA=2.18g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting jig.
TT 702. Channel 1

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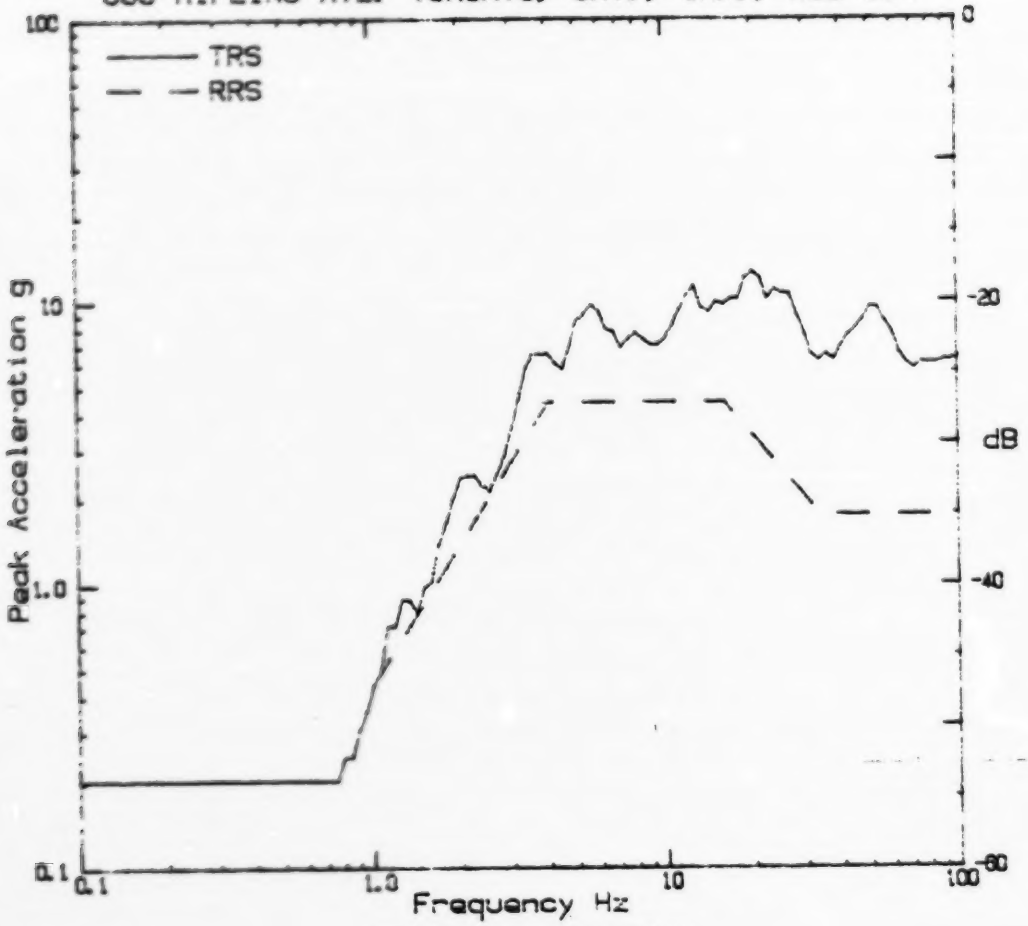


RESPONSE SPECTRUM

FIGURE 4

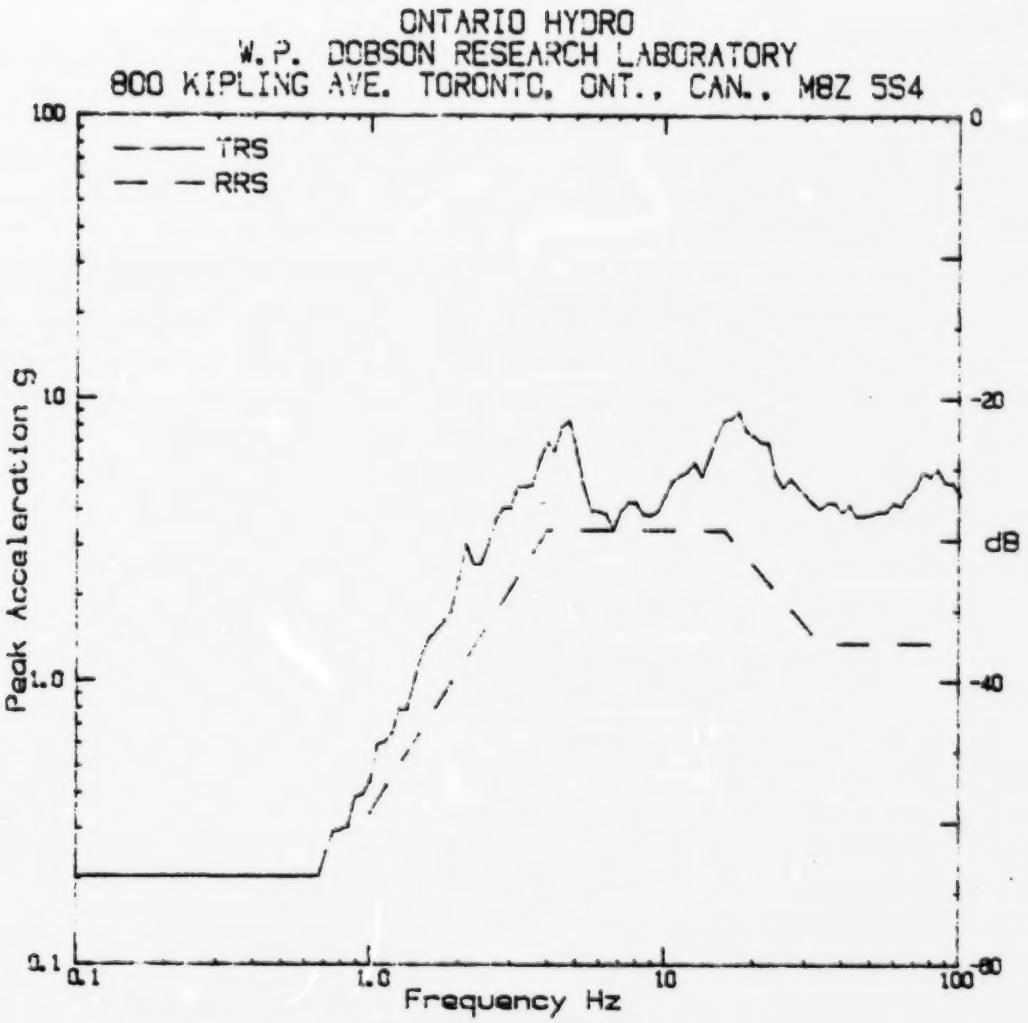
TEST ITEM
Station cells. Exide. Model EMP 13. Serial 8.

PARTICULARS
March 14/84. Time 11:28. Temp(°C) 23. Humidity(%) 39.
Press (kPa) 100.2. Graph 5111

SPECIFICATIONS
Spec IEEE 501. Conditions span 6.8. voltage & current monitored

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.77g

ACCELEROMETER
Wilcoxon. Serial S761. Range dB58. Location base-mounting jig.
TT 702. Channel 2



RESPONSE SPECTRUM

FIGURE 5

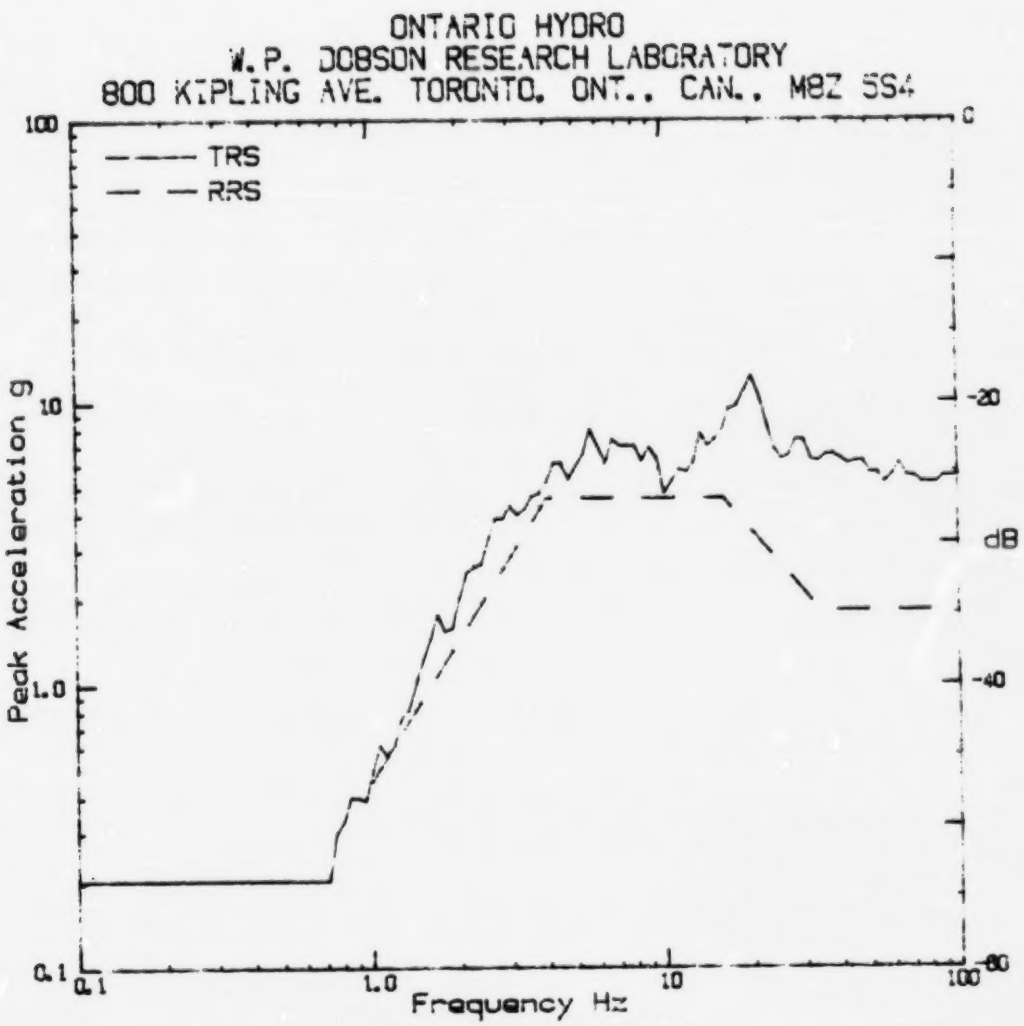
TEST ITEM
Station cells. Exide. Model EMP 13. Serial 8.

PARTICULARS
March 14/84. Time 11:28. Temp(°C) 23. Humidity(%) 38.
Press (kPa) 100.2. Graph 5112

SPECIFICATIONS
Spec IEEE 501. Conditions span 6.8. voltage & current monitored

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=1.37g

ACCELEROMETER
Wilcoxon. Serial S901. Range dB58. Location base-mounting jig.
TT 702. Channel 3



RESPONSE SPECTRUM

FIGURE 6

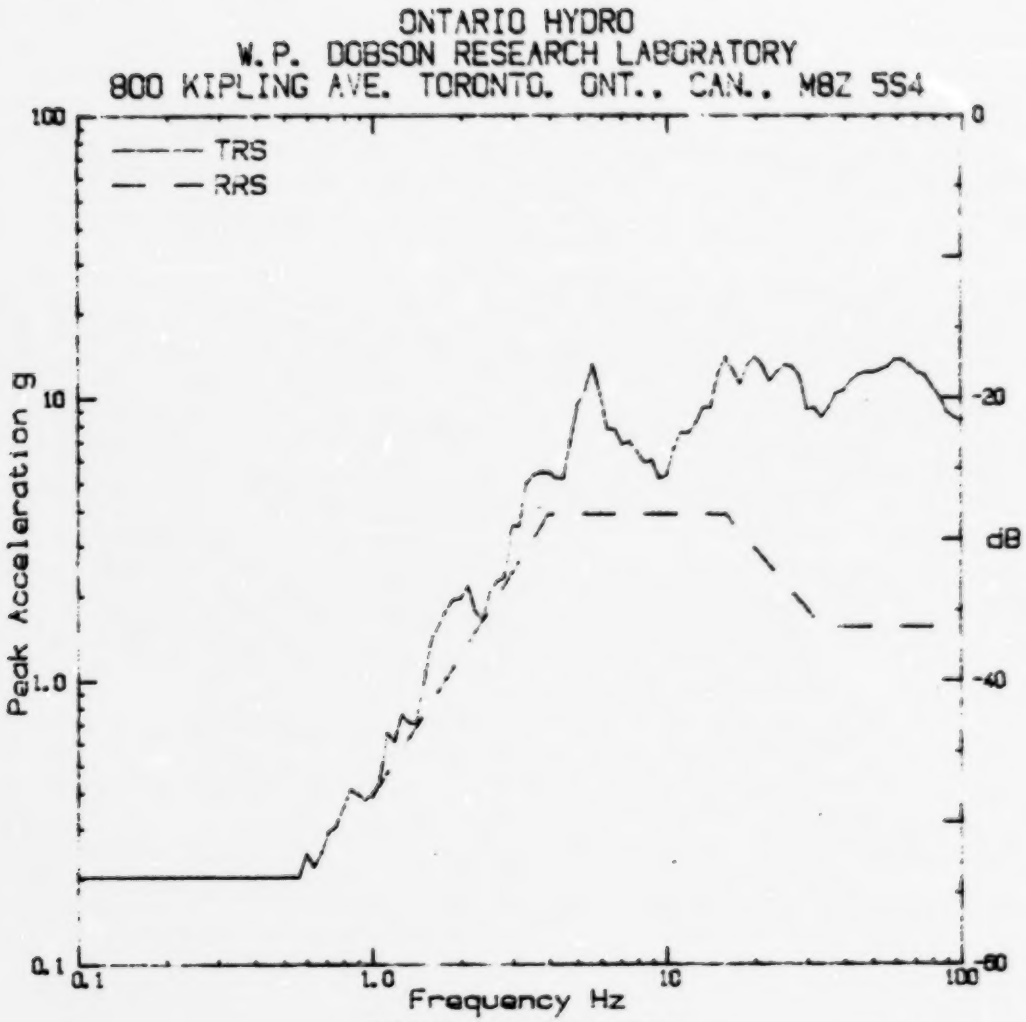
TEST ITEM
Station cells. Exide. Model EMP 13. Serial 1

PARTICULARS
March 14/84. Time 1:45. Temp('C) 23. Humidity(%) 39.
Press (kPa) 100.2. Graph 5118

SPECIFICATIONS
Specs IEEE 501. Conditions span 8.8. voltage & current monitored

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.83g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting jig.
TT 710. Channel 1



RESPONSE SPECTRUM

FIGURE 7

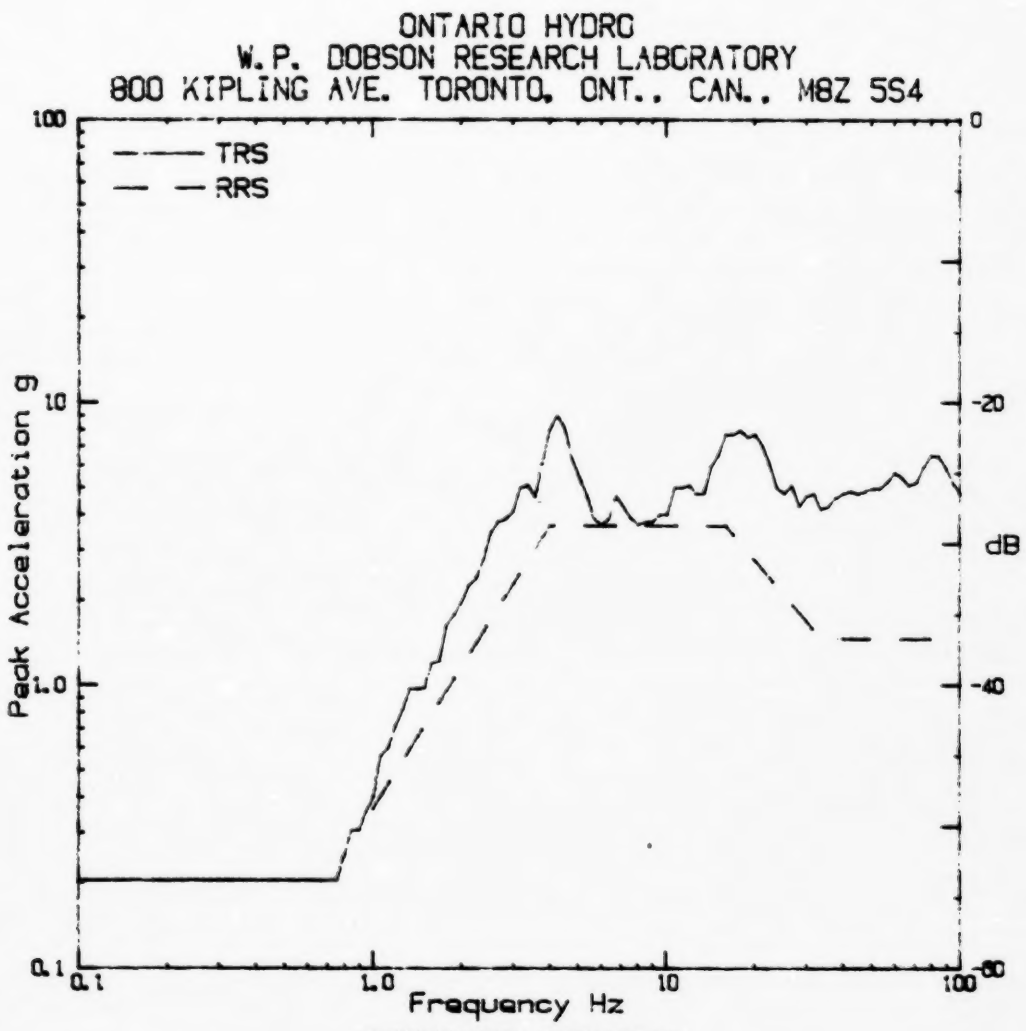
TEST ITEM
Station cells. Exide. Model EMP 13. Serial 1

PARTICULARS
March 14/84. Time 1:45. Temp(°C) 23. Humidity(%) 39.
Press (kPa) 100.2. Graph 5117

SPECIFICATIONS
Spec: IEEE 501. Conditions: span 6.8. voltage & current monitored

ANALYSIS
Type: Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker: tri-axial. ZPA=1.58g

ACCELEROMETER
Wilcoxon. Serial S761. Range dB58. Location base-mounting jig.
TT 710. Channel 2



RESPONSE SPECTRUM

FIGURE 8

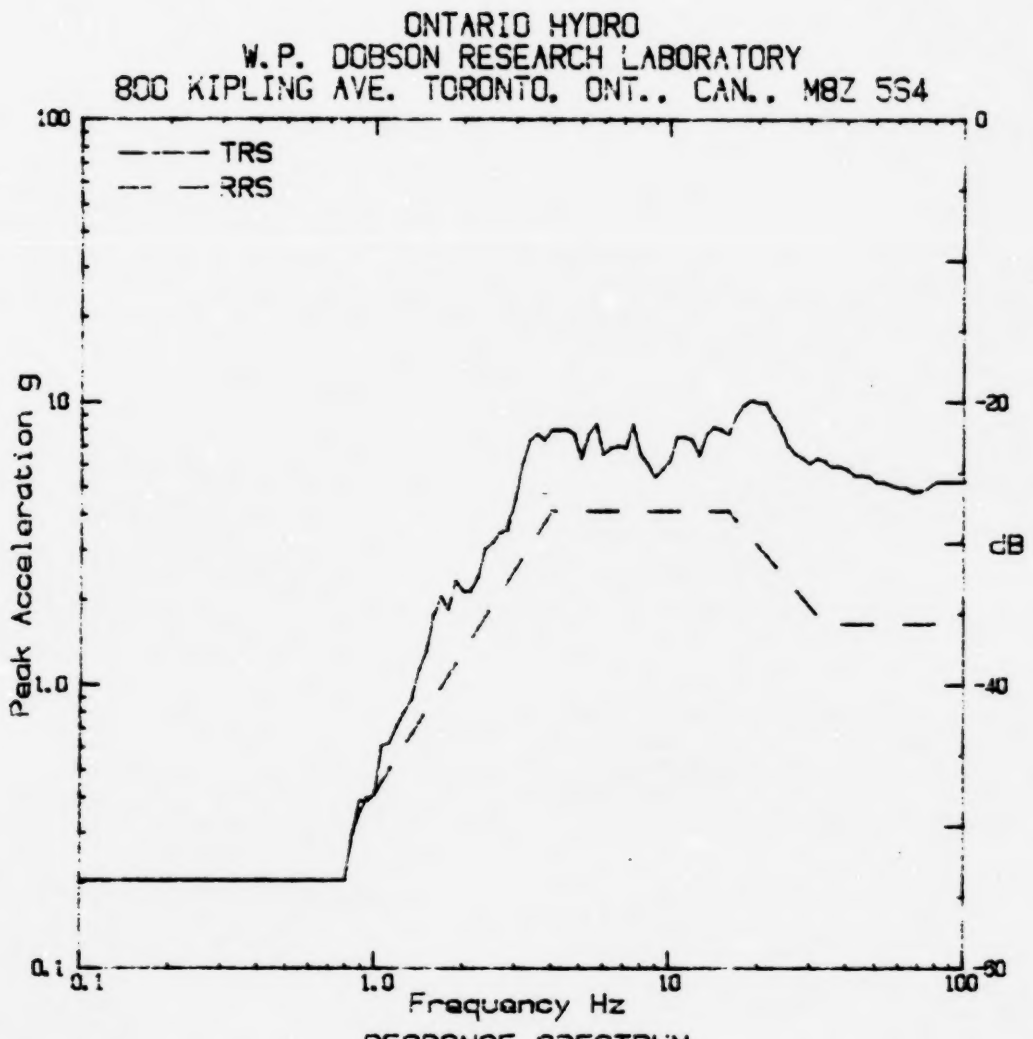
TEST ITEM
Station calls, Exide, Model EMP 13, Serial 1

PARTICULARS
March 14/84, Time 1:45, Temp(°C) 23, Humidity(%) 39,
Press (kPa) 100.2, Graph 5118

SPECIFICATIONS
Spec IEEE 501, Conditions span 6.8, voltage & current monitored

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.47g

ACCELEROMETER
Wilcoxon, Serial S901, Range dB58, Location base-mounting jig,
TT 710, Channel 3



RESPONSE SPECTRUM

FIGURE 9

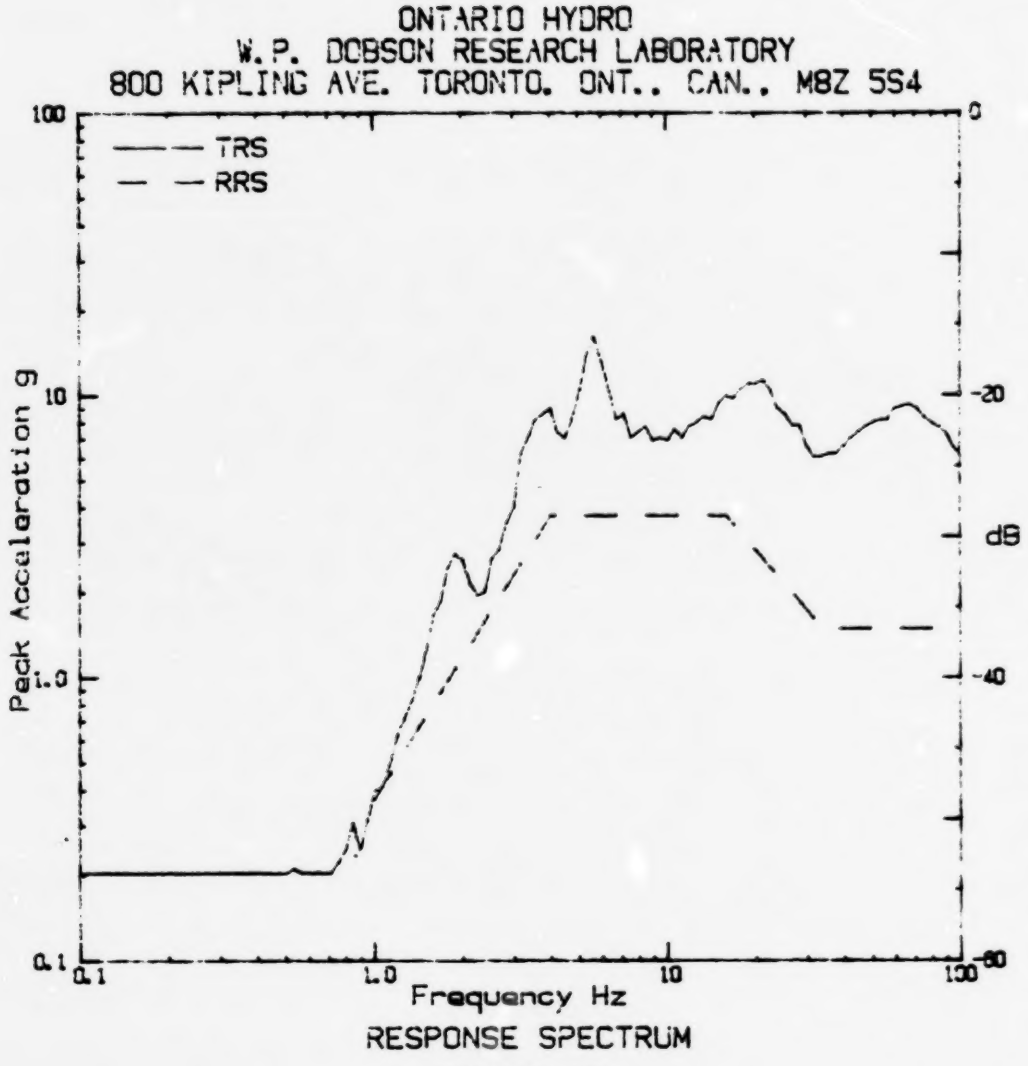
TEST ITEM
Station cells. Exide. Modal EMP 13. Serial 5.

PARTICULARS
March 14/84. Time 2:35. Temp(°C) 23. Humidity(%) 39.
Press (kPa) 100.2. Graph 5122

SPECIFICATIONS
Spec IEEE 501. Conditions span 6.8. voltage & current monitored

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.85g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting jig.
TT 720. Channel 1



RESPONSE SPECTRUM

FIGURE 10

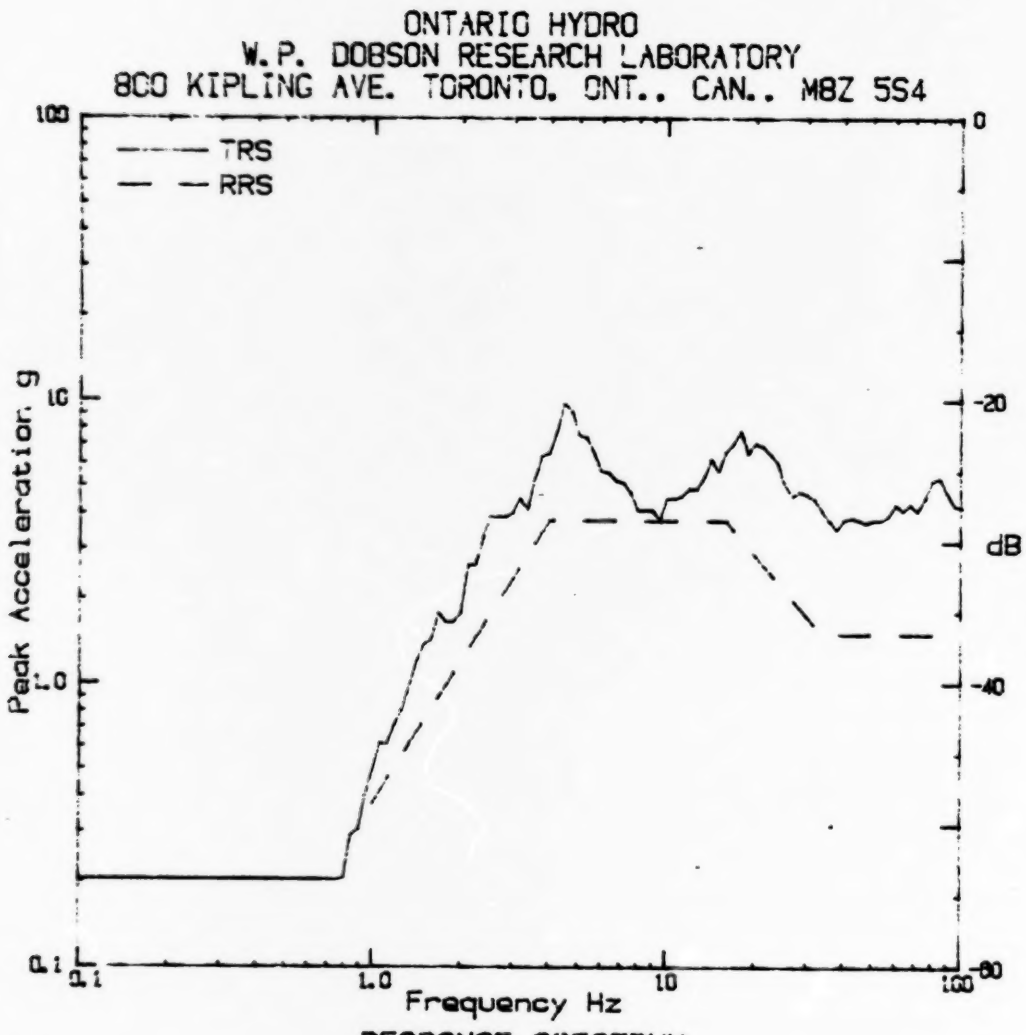
TEST ITEM
Station calls. Exide. Model EMP 13. Serial 5.

PARTICULARS
March 14/84. Time 2:35. Temp(°C) 23. Humidity(%) 39.
Press (kPa) 100.2. Graph 5123

SPECIFICATIONS
Specs IEEE 501. Conditions span 6.8. voltage & current monitored

ANALYSIS
Type Maximax. Damping (%) 5. B.W.= 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.5g

ACCELEROMETER
Wilcoxon. Serial S761. Range dB58. Location base-mounting jig.
TT 720. Channel 2



RESPONSE SPECTRUM

FIGURE 11

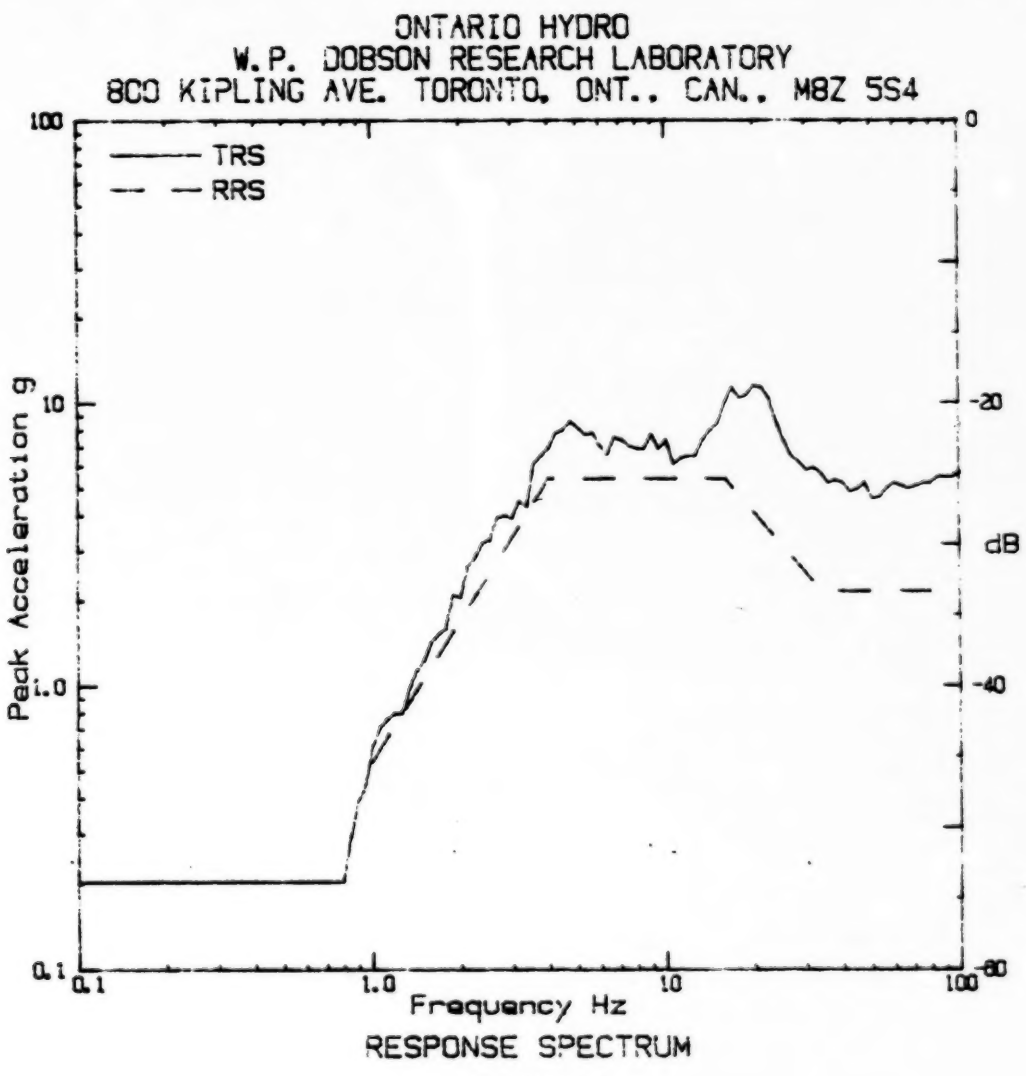
TEST ITEM
Station cells. Exide. Model EMP 13. Serial 5.

PARTICULARS
March 14/84. Time 2:35. Temp(°C) 23. Humidity(%) 39.
Press (kPa) 100.2. Graph 5124

SPECIFICATIONS
Specs IEEE 501. Conditions span 8.8. voltage & current monitored

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=1.5g

ACCELEROMETER
Wilcoxon. Serial S901. Range dB58. Location base-mounting jig.
TT 720. Channel 3



RESPONSE SPECTRUM

FIGURE 12

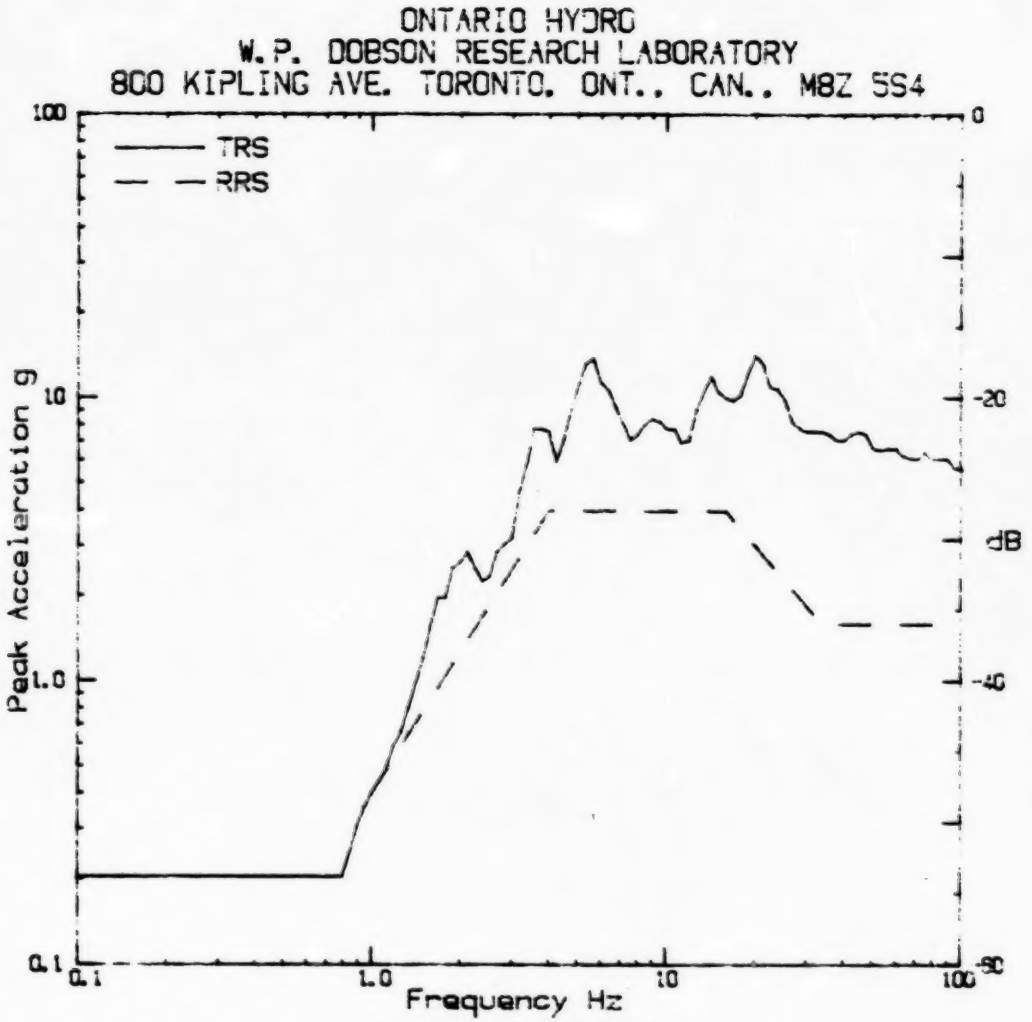
TEST ITEM
Station cells. Exide. Model EMP 13. Serial 11.

PARTICULARS
March 14/84. Time 3:00. Temp(°C) 23. Humidity(%) 39.
Press (kPa) 100.2. Graph 5128

SPECIFICATIONS
Specs IEEE 501. Conditions span 6.8. voltage & current monitored

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=2.16g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting jig.
TT 730. Channel 1



RESPONSE SPECTRUM

FIGURE 13

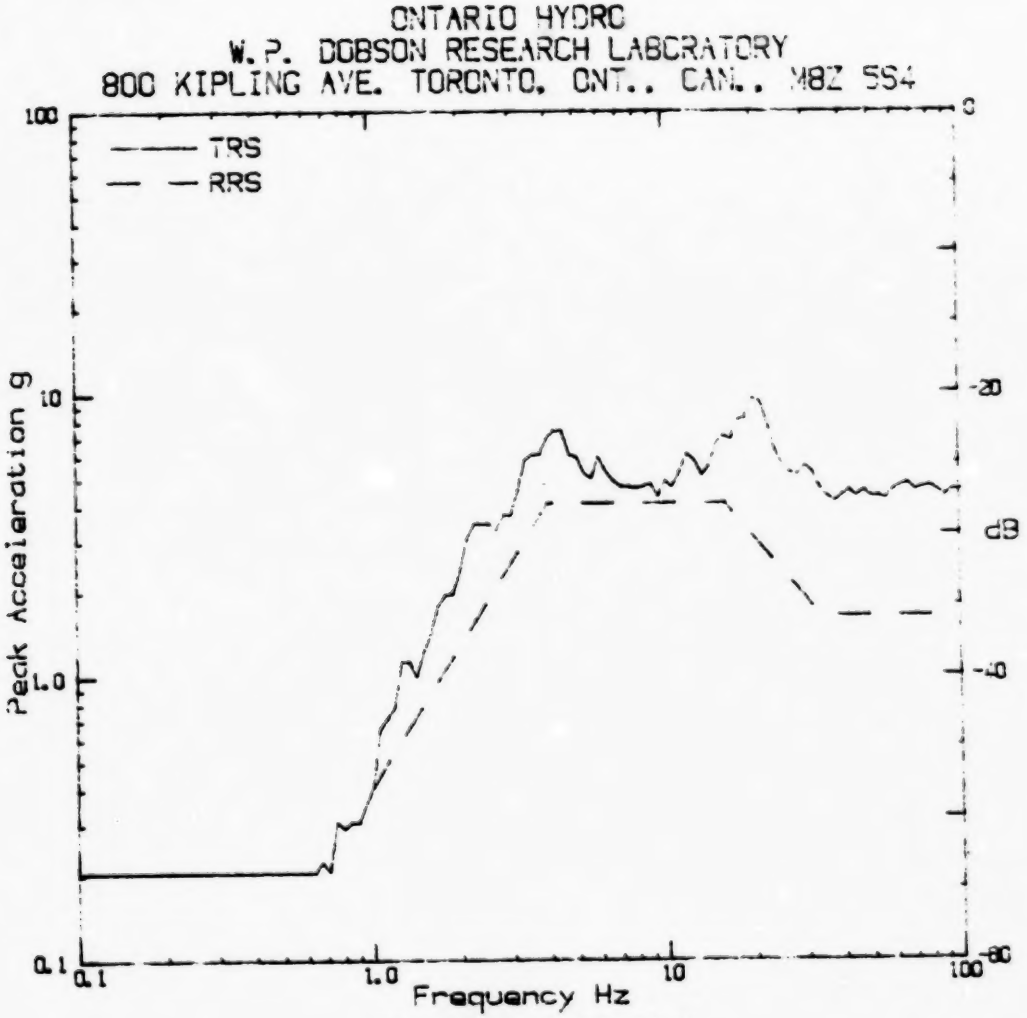
TEST ITEM
Station cells. Exide. Model EMP 13. Serial 11.

PARTICULARS
March 14/84. Time 3:00. Temp(°C) 23. Humidity(%) 39.
Press (kPa) 100.2. Graph 5129

SPECIFICATIONS
Specs IEEE 501. Conditions span 6.8. voltage & current monitored

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.59g

ACCELEROMETER
Wilcoxon. Serial S781. Range dB58. Location base-mounting jig.
TT 730. Channel 2



RESPONSE SPECTRUM

FIGURE 14

TEST ITEM
Station cells. Exide. Modal EMP 13. Serial 11.

PARTICULARS
March 14/84. Time 3:00. Temp(°C) 23. Humidity(%) 35.
Press (kPa) 100.2. Graph 5130

SPECIFICATIONS
Spec: IEEE 501. Conditions span 8.8. voltage & current monitored

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=1.63g

ACCELEROMETER
Wilcoxon. Serial S901. Range dB58. Location base-mounting jig.
TT 730. Channel 3

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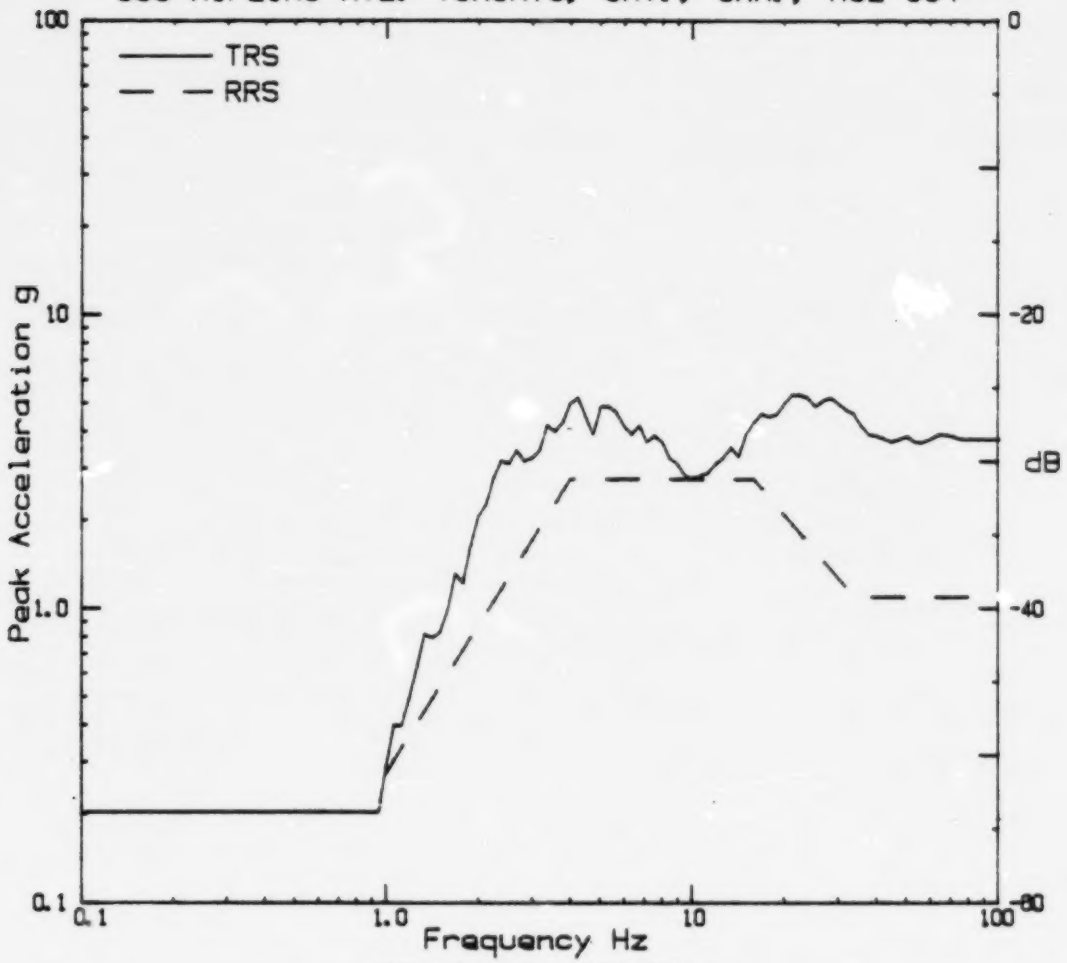
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 15

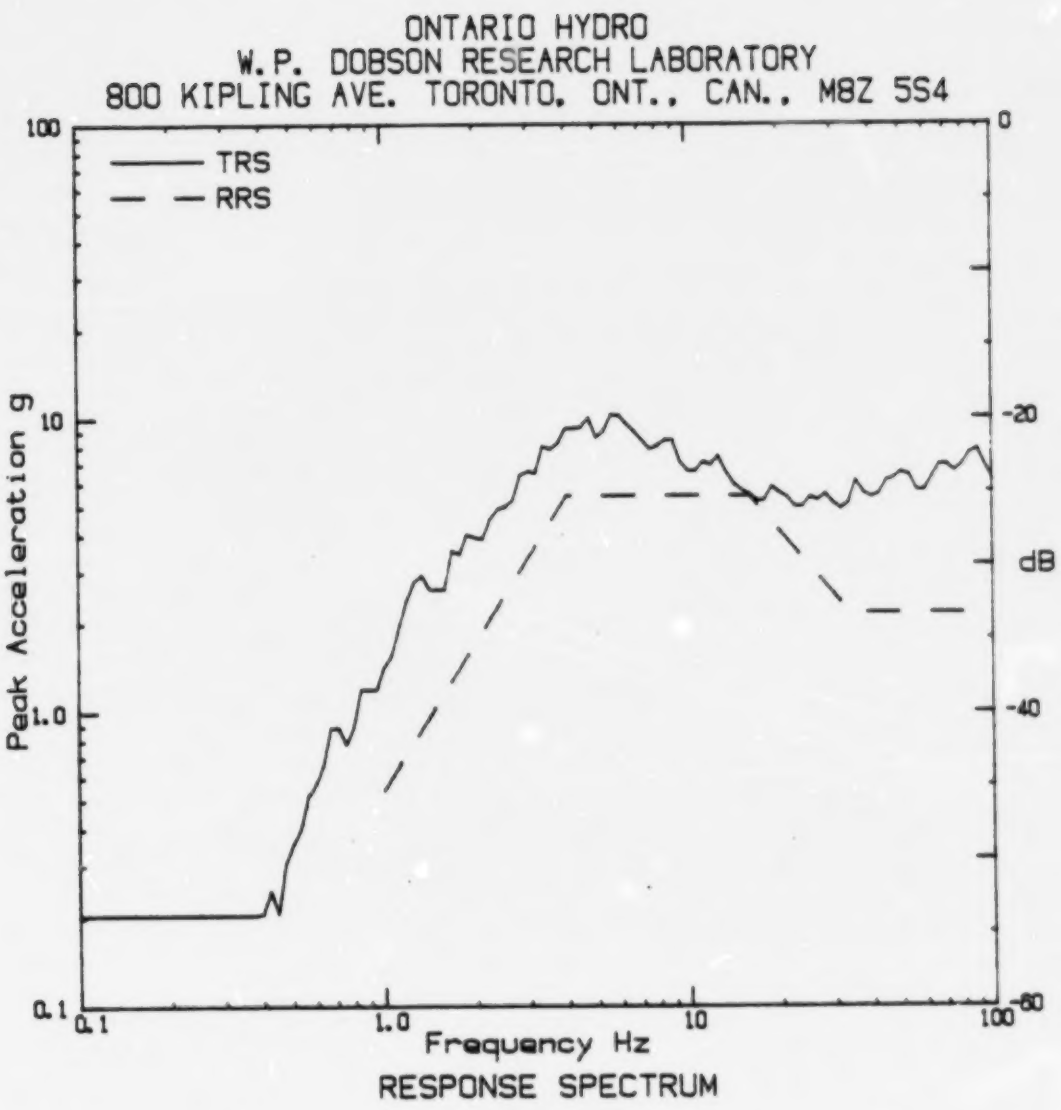
TEST ITEM
Station Cells & Rack, Exide, Model EMP-13, Serial 43,10,4,3,45

PARTICULARS
July 26/84, Time 3:08, Temp('C) 23, Humidity(%) 55, Press (kPa) 100,
Graph 5260

SPECIFICATIONS
Specs IEEE 501, Conditions operating : 1 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.1g

ACCELEROMETER
Wilcoxon, Serial S297, Range dB49, Location base-mounting plate,
Channel 1



RESPONSE SPECTRUM

FIGURE 16

TEST ITEM
Station Cells & Rack. Exide. Model EMP-13. Serial 43.10.4.3.45

PARTICULARS
July 26/84. Time 3:08. Temp('C) 23. Humidity(%) 55. Press (kPa) 100.
Graph 5261

SPECIFICATIONS
Spec: IEEE 501. Conditions operating ; 1 hour rate. span 7

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=2.17g

ACCELEROMETER
Wilcoxon. Serial S761. Range dB49. Location base-mounting plate.
Channel 2

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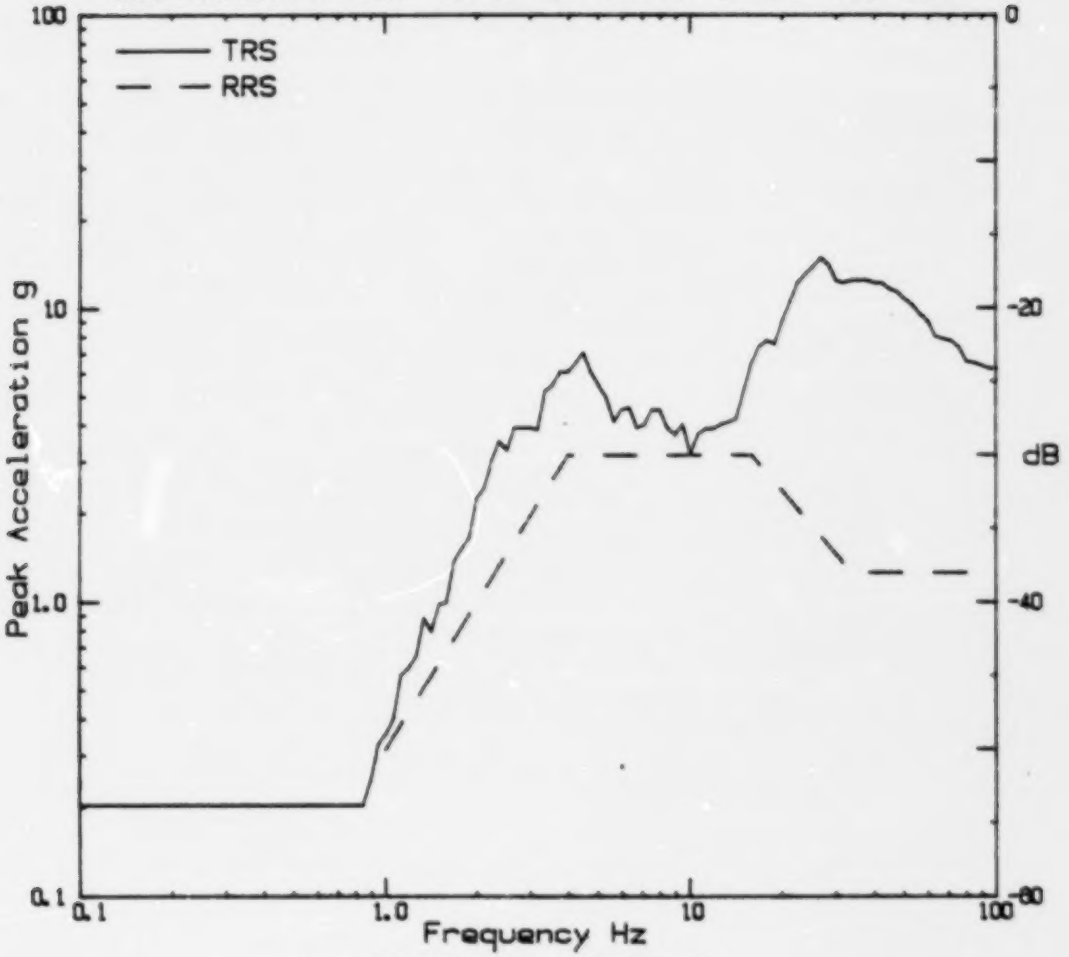

RESPONSE SPECTRUM

FIGURE 17

TEST ITEM
Station Cells & Rack, Exide, Model EMP-13, Serial 43.10.4.3.45

PARTICULARS
July 26/84, Time 3:08, Temp('C) 23, Humidity(%) 55, Press (kPa) 100,
Graph 5262

SPECIFICATIONS
Spec: IEEE 501, Conditions operating ; 1 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.26g

ACCELEROMETER
Wilcoxon, Serial S759, Range dB49, Location base-mounting plate,
Channel 3